QUALITY ASSURANCE CHALLENGES OF CREW ESCAPE SYSTEM

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Abstract

Quality Assurance (QA) of any launch vehicle system requires proactive involvement of QA engineer during all phases of the product life cycle starting from conceptual design, design finalization, product realization, and qualification till certification for flight. This paper highlights the major challenges faced by Quality Assurance teams during various phases of realization of Crew Escape System - Pad Abort Test (CES-PAT) in the areas of Avionics Systems. This paper also addresses the vital role played by the Quality Assurance process in bringing out major issues faced during system realization, the lessons learned and the corrective actions implemented.

Keywords*: Quality Assurance, PAT, CES, Avionics, WIS, Radar Altimeter, Testing, MDTT*

Introduction

Human Space Flight (HSP) mission requires development of certain critical technologies. Crew Escape System (CES) is one among them as crew safety is of utmost importance during all phases of mission. The CES [1] ensures safety of crew in case of exigencies at launch pad or during the initial ascent phase of flight. CES [3] was successfully demonstrated in the Pad Abort Test (PAT) at Shriharikotta on 5th July, 2018, where a launch pad abort scenario was simulated and the CES [1] carried the Crew Module (CM) to a safe distance, and stressfully landed as well as recovered from Bay of Bengal. After design of all the systems, QA teams carried out the Failure Mode Effects and Criticality Analysis (FMECA), results of which were provided as inputs for design improvement and generation of qualification and acceptance plan. The plan called for detailed testing at integrated level which demanded utilization of large number of facilities, resources and time to complete all planned tests. These tests, in addition to ensuring health of the systems, were also useful in identifying and bringing out many inadequacies in the systems, which were subsequently analyses and appropriate corrective actions implemented for successful flight.

The test philosophy adopted for qualifying and accepting the system is "Test as you fly and fly as you test" concept. A detailed qualification test plan was prepared in line with this concept.

Crew Module Avionics Subsystems

A High Dynamic Inertial Navigation System (HDINS) was newly developed for PAT to cater the rates, of the order of 150°/s and acceleration of 15g. A Crew Escape Sequencer (CRES) was used to execute sequencing commands [4]. Timing information of sequencing commands was stored in EEPROM in CRES and provision was enabled for programming at test site and launch pad also. Wireless Instrumentation System (WIS), Multi-function Digital Telemetry Transmitter (MDTT), Mobile Satellite Service Terminal (MSST), Standard Definition Video Data Recorder (SD-VDR) were introduced as experimental payloads.

The design finalization of new avionics systems, qualification, test plan generation and validation of system in integrated environment were really challenging in the quality assurance of PAT avionics systems [4].

Evaluation of Radar Altimeter Performance in Integrated Environment

Ka band Radar Altimeter (RA) was mounted on the Crew Module (CM) bottom cover to measure the altitude accurately. To validate RA performance in the CM inte-

grated condition, the CM was taken to a known height using crane. Under this condition, the altitude measured was found to be high corresponding to the multiple reflected signals with higher signal strength. As a result, the RA signal was noticed to be locked on to the reflected signals at high altitude leading to errors in altitude measurement.

This was alleviated using modified RA algorithm in such a way that it locked on to the smallest altitude. In this way, the problem of getting locked onto multiple reflections was avoided.

A reflection free environment altitude test was also devised for RA by mounting reflection absorbent foam on crane used for simulating altitude input. Correct measurement was ensured with these two modifications.

During all integrated level checks, the Radar Altimeter was mounted on bottom cover, and it was ensured that the RF portion was put OFF to prevent high reflected signal strength reaching RA input filter. In flight also, RF portion was put ON after 5s by sending MAP ON / MAP OFF programming commands from checkout in Automatic Launch Sequence (ALS) mode.

In-situ Programming of Crew Escape Sequencer

Crew Escape Sequencer (CRES) was used for initiating the sequencing commands. The time tagged sequencing command information was stored in an EEPROM in CRES. On the reception of trigger signal from checkout, the commands were executed based on the table preloaded in EEPROM.

Since there was no active control for CES, the sequencing timing was fixed based on mission studies and the launch day wind had a significant role in determining the time of executing pitch motor ignition command to swerve the Crew Escape Sequencer away from land to target its impact on pre-determined site in Bay of Bengal. This demanded an in-situ programming of CRES EEPROM to change the sequencing timing information. This was achieved by providing a programming interface based on a laptop system. The write enable signal from FPGA to EEPROM was routed through a looping connector to allow EEPROM write. The CRES was reprogrammed at SHAR using this interface for sequencing timing change.

The EEPROM interface was verified in lab and during Crew Module sub-assembly levels. Initially with longer cable length during programming at SHAR, the EEPROM write was not effective due to insufficient drive capability for the programming interface to maintain write signal timing requirement. The only additional difference between lab programming and SHAR programming set-up was in the long length of looping harness (approx. 2m) from package to the checkout interface termination connector. The write enable signal is routed from the FPGA to EEPROM through a 54LS14 buffer via the looping connector. This write enable signal is a high to low pulse for every word write to EEPROM of particular pulse width (order of μs). This low state of corresponding pulse width is essential to ensure proper write operation. The long cable introduces additional capacitance thereby loading the buffer output which results in a weak zero and hence, write was ineffective. This brought out the need for characterization of all interfaces with actual cable length.

Testing and Routing in Explosive Environment

The Crew Escape System (CES) had 92 squibs for executing several pyro functions like ignition of different motors: Low Altitude Escape Motor (LEM), High Altitude Escape Motor (HEM), Pitch Motor (PM), CM Jettisoning Motor (CJM), separation of Crew Escape System - Crew Module (CES-CM) and parachute deployment related commands [2].

The parachute related pyros were already assembled in Crew Module during system level checks. Crew Module - Crew Module Fairing (CM-CMF) integrated checks and Crew Module - Crew Escape Sequencer (CM-CES), integrated checks took place in an active pyro environment.

The pyro electrical commanding circuit with safety breaks is given in Fig.1. All the safety breaks in pyro circuits sequencer SAFE/ARM, battery ON/OFF, Squib SAFE/ARM and ARM PLUG were exercised cautiously during all sequencing checks.

The motor for providing pitch to the vehicle was assembled in the Pitch Motor compartment at final stage and hence, the routing of pitch motor igniter squib to the sequencer and strain gauge for detecting motor ignition was done at the launch pad. Since the vehicle is in fully integrated condition with all the motors assembled, extreme care was taken for the routing activity. All safety precautions were taken and the routing activity was planned step by step and implemented. A test plan for verifying the integrity of harness at every step with an emphasis on safety was planned and implemented.

Sign Convention Verification of High Dynamic Inertial Navigation System (HDINS)

HDINS had 3 Fiber Optic Gyros for sensing high angular rates of the order of 150°/s and 3 Ceramic Servo Accelerometers (CSA) for measuring acceleration up to 15g. The high acceleration experienced during firing of escape motors [2] and high rates during deployment of parachutes after CM-CES separation posed this high dynamic range requirement.

The sign conventions of sensors were specifically verified during system level checks and the sensors performed as expected during the Pad Abort Test. Maximum rate experienced by the gyro channels was 149.13°/s in Pitch, 100.46°/s in Yaw and 63.65°/s in Roll, during Main chute deployment. Maximum longitudinal acceleration was 96.2 m/s^2 at 0.48s. Maximum acceleration In X and Y axis was 20.63m/s^2 and 10.84 m/s^2 respectively, around 54s, during Main chute deployment.

System Level FMECA

The CES configuration is equipped with a number of solid motors and there was no active control system for attitude control [2]. So, all aspects related to launch pad safety during preparations and mission safety during launch operations were critically studied.

The different failure scenario which may lead to impact on land was exhaustively assessed. System level FMECA was carried out on all avionic systems to ensure safe impact under different failure modes like non ignition of motors, failure of separation system etc. Safety interlocks were introduced like checking of grid fin deployed angle potentiometer feedback in checkout as part of Automatic Launch Sequence (ALS). It was ensured that grid fins are deployed prior to CM-SM separation and separation command was issued only after satisfactory deployment and final locking of grid fins in position.

Checkout Operations from Unified Checkout System

During all sub-assembly and system level checks for PAT mission, a unified checkout console was used for powering ON, monitoring the telemetry parameters, issuing safing commands and carrying out tests for evaluating performance of avionics systems. The functions of Navigation Systems Console, Pyro and Power Systems Console, RF and Tele-command Console, Telemetry Console and Automatic Launch Sequence (ALS) Console of a conventional launch vehicle checkout system were integrated in the Unified Checkout Console (UFCC). Different display nodes were provided for catering to different test requirements.

Evaluation of UFCC system and preparation of checklist enlisting all operations and safety interlocks was carried out exhaustively. Timeline of all the test day activities was prepared and pre-requisites before each test were confirmed during ALS data file verification. The Unified Checkout Console successfully executed all launch day activities in automated fashion from Package Power ON to Lift off in Pre ALS mode from T-5 hrs to T-8 mins and in ALS mode from T-8 mins to T0.

Structural Measurements Instrumentation and Routing of Sensors in CM and CMF

HSP-PAT instrumentation was challenging with about 250 structural measurements. The strain measurements accounted for the major share with about 130 measurements. A separate data acquisition unit with provision for digital tuning was used for strain measurement.

The mounting of sensors and routing of harness in limited access areas inside the Crew Module Fairing (CMF) after the assembly of HEM and LEM motors and subsequent harness integrity verification was challenging. The harnessing was carefully inspected at every step and integrity was ensured. Moreover, the harness routing was carefully planned and implemented so that the aerodynamic performance of the CMF is not affected. Sufficient thermal protection was also provided to the harness as well as sensors in CMF and CM against the flames deflected from HEM and LEM nozzles at lift-off.

RF Experimental Payloads Evaluation

The RF experimental payloads for PAT mission were MSST, MDTT and WIS. The integrated test set up for these payloads was designed along with mini SBT and NavIC receiver antenna re-radiation set up.

WIS consists of one Wireless Base Station (WBS) and four Wireless Sensor Nodes (WSN). WIS could reduce the harness mass considerably, with potential payload benefits. The WBS receives data from each WSN through two diverse RF links (2425MHz and 2475MHz) and data is posted in two RS485 links for telemetry. 24 parameters including Acceleration, Rate, Temperature, Voltage and RF health parameters were measured. Mounting of WBS

and WSN inside CM was suitably planned and implemented to minimize interference and signal fading. All analog parameters acquiredbyWIS showed good match with functional chain parameters except accelerometer outputs where largespikes were seen throughout.

MDTT is an Offset Quadrature Phase Shift Keying (OQPSK) digital telemetry transmitter with turbo coding which enables reduction of RF transmitter power and DC power consumption with minimum Bit Error Rate (BER). This 0.5W transmitter, with 2 Mbps turbo coded data, was used as third telemetry chain at 2259 MHz telemetering same parameters as the functional second telemetry chain. The processed data matched with functional telemetry chain except during data loss period.

The RF packages are housed inside CM, enclosed by CMF. Transfer antennas mounted on the CMF were used for radiating data till CMF separation. Interference studies were conducted and optimum placement of antennas were finalized. Patch antennas were used to preserve the aerodynamic shape of the module.

RF compatibility checks with CMF, transfer antennas and Re-radiation setup was planned as in Fig.2 and successfully implemented.

Waterproofing of Avionics Packages, Batteries and Harness in CM

The CM which houses the avionics packages and batteries landed in the Bay of Bengal, from where it was retrieved. Since CM lands in the sea, sufficient protection was provided to crew module against spills and the bottom portion was made completely water proof. Avionics packages from which data has to be retrieved were hermetically sealed. To protect the packages against water seepage, the D-type connectors of packages were waterproofed using Room Temperature Vulcanising (RTV) compound. Plasmask was provided to D-38999 connectors of batteries to prevent any short-circuit in the battery terminals.

Environmental Test for Avionics Subsystem

All avionics packages were qualified to higher shock environments, considering high shock levels expected during CM - CES separation.

The SRS test level given in thrust axis is given in Table-1.

Table-1 : Thrust Axis SRS Level

Excitation Axis	Frequency	g (Q = 25)
ZZ	100	5
	1300	500
	2000	500

Additional EMI test with MDTT, WIS, MSST, mini SBT frequencies were carried out during Test and Evaluation of all avionics packages. Performance was evaluated in integrated EMI environment also.

Conclusion

Pad Abort Test was a technology demonstrator intended to flight test the Crew Escape System, which is a critical technology required for an abort at the launch pad and taking the crew to safety [1]. The successful Pad Abort Test has given confidence and valuable inputs for the forthcoming Human Space Mission. The successful completion of this mission has demonstrated many novel and critical technologies including CES Escape motors, Deceleration system and proven adequacy of vehicle configuration and design to achieve required altitude, range and acceleration profile for meeting exigencies at launch pad. High Dynamic INS, Wireless Instrumentation System and MDTT could also be proven in flight. All the complex subsystems involved should function in complete synchronization, for achieving success of similar magnitude. This has to be ascertained through exhaustive validations of all subsystems to ensure correctness and predictability under different scenarios. The validations not only provided the QA engineers with many challenges to overcome but also presented many opportunities to learn such complex technologies.

Acknowledgement

We would like to acknowledge our colleagues from Quality Division Avionics Systems, VSSC, namely Shri Noel Philip, Shri P. T. Nelson and Shri Muhammed Salih Sahib, for their valuable suggestions and inputs for this paper.

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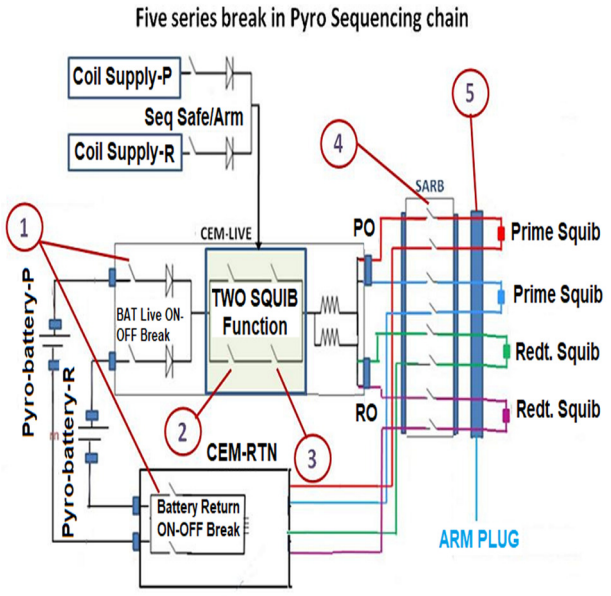

Fig.1 Safety Breaks in Sequencing Chain

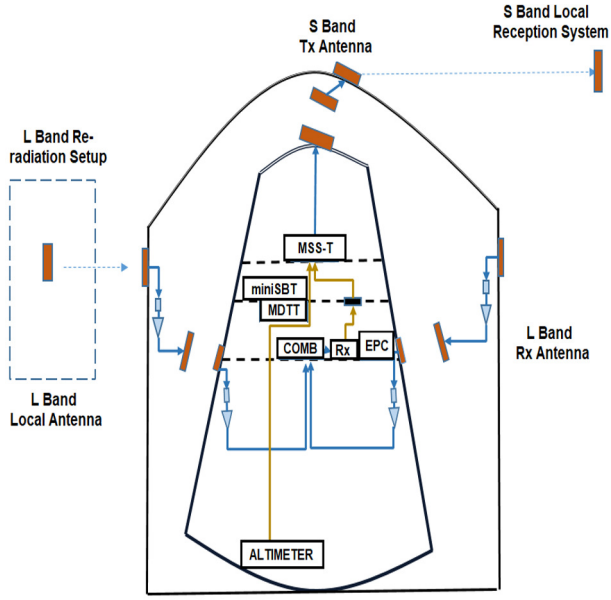

Fig.2 Transfer Antenna Set-up for RF Tests